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Incipient Fault Detection Analysis of Power Transformer by Fuzzy Inference System

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Abstract: This paper deals with fault diagnosis of Power Transformer by taking the data of oil samples. Generally, conventional dissolved gas analysis techniques are used to determine the incipient faults by analyzing different gas ratios of the faulty oil samples. Here, the proposed fuzzy interference rules have been applied on the available data of faultyoil gas samples. With the help of fuzzy rules, the type of fault is detected successfully by comparing it with the standard tables of Dissolved Gas Analysis methods like Doernen burg Ratio, Rogers Ratio and IEEE table. The fuzzy rules and its implementation have been carried out in MATLAB software.
Keywords: Dissolved Gas Analysis (DGA), fuzzy interference System (FIS),Input Output(I/O).

I. INTRODUCTION

Power transformer is one of the major equipment for transmission and distribution electrical power system at various voltage levels. The transformer breakdown or failurecan be occurs due to various types of electrical, mechanical, chemical and thermal stresses. A large power transformer are generally oil immerged which is highly flammable and need to be diagnose frequently. The continuous operation of transformer will result into an aging and deterioration effects on transformer oil which are the major problematic issues and play important role in economical operation of any electrical System. So in order to avoid transformer failure due to incipient fault a continuous monitoring techniques have to be applied periodically [1,2].

A highly refined mineral oil is used in transformer which is thermally stable at high temperatures and has excellent insulating properties. C_nH_{2n+2}aregeneral molecular formula for mineral oil insulating fluid. The value of 'n' for saturated hydrocarbon ranges from 20 to 40[2,10].The various type of fault gases includes Methane (CH_4),Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2), Hydrogen(H_2)**,** Carbon monoxide (CO),Carbon dioxide (CO_2), Nitrogen (N_2),Oxygen(O_2)[3,8].

From the gas generation chart [4,9] it can be seen that there are different types of faults which occurs in transformer oil like Corona, Pyrolysis and Arcing etc. The Corona is a low energy electrical fault with Hydrogen as a major by product. In Pyrolysis, Ethylene and Methane are the major decomposition gases beside there are small amount of Hydrogen and Ethane. The intensity of energy dissipation is more in Pyrolysis than in Corona. The Arcing H_2, C_2H_2 (CH_4, C_2H_6, C_2H_4) occurs when a large amount of hydrogen and acetylene are produced. Arcing occurs during high current and temperature. The intensity of dissipation is highest in arcing followed by heating and Corona.

II. DISSOLVED GAS ANALYSIS (DGA) METHODS

Dissolved Gas Analysis (DGA) is important and reliable method for assessment of incipient faults due to aging and deterioration in transformer oil [1]. Because of various internal stresses, insulating materials and oils present in transformers have been found to deteriorate which results in generation of combustible or harmful gases. The various DGA methods are used to determine the amount of gases generated and dissolved in oil filled Power transformers which are the main causes of incipient fault. The DGA methods detect the causes of incipient fault by assessing oil health conditions so that the necessary corrective measure action can be performed. Among the available DGA techniques the Doernen burg's Ratio and Rogers Ratio methods are generally used for diagnosis. For incipient fault detection these dissolved gas analysis (DGA) methods are very efficient tool for daily monitoring of the power transformers and other applications [5].

A. Roger Ratio Method

The Roger's method utilizes four gas ratios: CH_4/H_2 (i), C_2H_6/CH_4 (j), C_2H_4/C_2H_6 (k) and C_2H_2/C_2H_4 (l). Diagnosis of faults is accomplished via a simple coding scheme based on ranges of the ratios and the combination of the coding gives ten different types of transformer faults [6]. The type of faults based on the code is shown in table 1:

Table 1: Roger Ratio Chart

Code of Range of Ratios	Ratios of Characteristics Gases			
	CH_4/H_2 (i)	C_2H_6/CH_4 (j)	C_2H_4/C_2H_6 (k)	C_2H_2/C_2H_4 (l)
<=0.1	5	-	-	-
<0.5	0	-	-	-
>0.1,<1.0	0	0	0	0
>=1.0,<3.0	1	1	1	1
>=3.0	2	-	2	2
Characteristics Fault	CH_4/H_2 (i)	C_2H_6/CH_4 (j)	C_2H_4/C_2H_6 (k)	C_2H_2/C_2H_4 (l)
Normal Deterioration	0	0	0	0
Slight Overheating <150^{0}C	1-2	0	0	0
Overheating 150^{0}C -200^{0}C	1-2	1	0	0
Overheating 200^{0}C -300^{0}C	0	1	0	0
General Conductor Overheating	0	0	1	0
Winding Circulating Currents	1	0	1	0
Core &Tank Circulating Currents, Overheated Joints	1	0	2	0
Flashover Without Power Follow Through	0	0	0	1
Arc With Power Follow Through	0	0	1-2	1-2
Continuous Sparking Floating Potential	0	0	2	2

B. *Doernenburg Ratio Method*

This method utilizes the gas concentration from ratio of CH_4 / H_2 (R1), C_2H_2/C_2H_4 (R2), C_2H_2/ CH_4 (R3) and C_2H_6/C_2H_2 (R4). The value of the gases at first must exceed the concentration L1to ascertain whether there is really a problem with the unit and then whether there is sufficient generation of each gas for the ratio analysis to be applicable. Table 4.1.3 shows the key gases and their concentration L1 [7].

Table 2: Concentration L1for Doernenburg Ratio Method

Key Gas	Concentration L1 (ppm)
Hydrogen(H_2)	100
Methane(CH_4)	120
Carbon monoxide(CO)	350
Acetylene(C_2H_2)	35
Ethylene(C_2H_4)	50
Ethane(C_2H_6)	65

According to IEEE Standard [7,10], the step-by-step procedure to diagnose faults using Doernenburg ratio method is:

Step 1: Gas concentrations are obtained by extracting the gases and separating them by chromatograph (Any of various techniques for the separation of complex mixtures that rely on the differential affinities of substances for a gas or liquid mobile medium and for a stationary adsorbing medium through which they pass, such as paper, gelatin, or magnesia)

Step 2: If at least one of the gas concentrations (in ppm) for H_2, CH_4 , C_2H_2, and C_2H_4 exceeds twice the values for limit L1(see table 4.1.3) and one of the other three gases exceeds the values for limit L1, the unit is considered faulty; proceed to Step 3.
Step 3: Determining validity of ratio procedure: If at least one of the gases in eachratio CH_4 / H_2 (R1), C_2H_2/C_2H_4 (R2), C_2H_2/ CH_4 (R3) and C_2H_6/C_2H_2 (R4) exceeds limit L1, the ratio procedure is valid. Otherwise, the ratios are not significant, and the unit should be resampling and investigated by alternative procedures.
Step 4: Assuming that the ratio analysis is valid, each successive ratio is compared to the values obtained from table 2 in the order of ratio CH_4/H_2 (R1), C_2H_2/C_2H_4 (R2), C_2H_2/CH_4 (R3) and C_2H_6/C_2H_2 (R4).
Step 5: If all succeeding ratios for a specific fault type fall within the values (column) given in Table 2, the suggested diagnosis is valid.
Diagnosis of faults is accomplished via a simple coding scheme based on ranges of the ratios as shown in tables 1& 2 which indicate the fault diagnosis for Doerenburg Ratio Method.

III. FUZZY LOGIC SYSTEM

A fuzzy system constitutes the fuzzy set which generalizes the classical set to allow partial membership. A fuzzy set is defined by a function that maps objects in a domain of concern to their membership value in the set. Such a function is called the Membership Function. Due to wide range of applications fuzzy IF-THEN rule is most visible one, fuzzy IF-THEN rule also plays a critical role in industrial applications ranging from consumer products. Structure of Fuzzy Rules: IF<antecedent> THEN<consequent>. Here, antecedent describes a condition and the consequent describes a conclusion. The algorithm of fuzzy rule-based inference consists of three basic steps and an additional optional step.
Fuzzy Matching: Calculating the degree to which the input data match the condition of the fuzzy rules.
Inference: Calculating the rule's conclusion based on its matching degree.
Combination: Combine the conclusion inferred by all fuzzy rules into a final conclusion.
(Optional) Defuzzification: For application that need a crisp output (e.g., in control system), an additional step is used to convert a fuzzy conclusion into a crisp one.

A. *Proposed Fuzzy Inference System*

The proposed ogers ratio based fuzzy inference system have been developedwith four set of fuzzy inputs variables of their respective membership functions . The system has total five fuzzy variables (Four input variables and single output variable) for the incipient fault detection in transformer. Each fuzzy variable has 10 membership functions with each membership function is triangular shape because of its economical feature as shown in figure1. Once the shape of membership function is selected, one has to map each element of the term set on the domain of the corresponding linguistic variable. Also there are 10 fuzzy sets for output variable which are equally spaced on the output range of 0 to 2 volts.

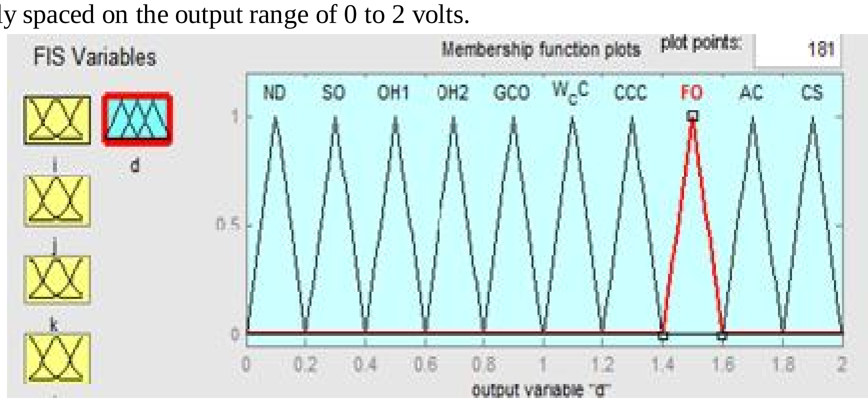

Figure 1:Variable Description of Rogers ratio based fuzzy inferencesystem.

In this system, the different values of Rogers gas ratios for faulty oil sample are converted into fuzzifedinput variables (I,j,k,l)and a knowledge based rule set of if-then linguistic structures applied which give correspoding fuzzy output variable(d) whose defuzzified value will identifed the type of incipient fault.With the selection of appropiate fuzzy inference system a crisp value of output can be derived for the determination of fault.

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IV. SIMULATION RESULTS ANS DISCUSSIONS

The effectiveness of Rogers ratio based fuzzy inference system has been demonstrated by testing the DGA results of various transformer's oil samples. Here,the data of eight transformer are tested by using Doernenberg and Rogers ratio methods as shown in tables 3&4.

Table3: Physical Test data of transformer's oil samples.

Sample No.	Power Transformer Detail	Hydrogen (H_2)	Oxygen (O_2)	Nitrogen (N_2)	Methane (CH_4)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Acetylene (C_2H_2)	CO_2	CO
1.	22/31.5MVA 220/6.9KV Sr.no.120195	13	18230	27275	6	4	2	TRACE<1	1452	394
2.	31.5MVA 16.5/6.9KV Sr.no.24140	15	2145	11478	8	1	5	NIL	390	51
3.	2MVA 6.6/433V Sr.no.37928	10	2616	31876	9	8	22	11	2689	219
4.	2MVA 6.6/433V Sr.no.37929	8	8564	19487	18	2	2	10	2136	152
5.	2MVA 6.6/433V Sr.no.37934	7	3847	11247	2	1	TRACE<1	2	1654	169
6.	22/31.5MVA 220/6.9KV Sr.no.120195	15	15475	28432	13	10	15	TRACE<1	2312	220
7.	22/31.5MVA 220/6.9KV Sr.no.120167	13	3265	28432	13	2	TRACE<1	20	2312	230
8	2MVA 6.6/433V Sr.no.37933	14	5215	21412	11	3	TRACE<1	18	1214	120

Table4:ROGER'S RATIO ANALYSIS(With Normalized input variable for oil samples)

Sample no	CH_4 / H_2 (i)	C_2H_6 /CH_4 (j)	C_2H_4/C_2H_6 (k)	C_2H_2/C_2H_4 (l)
1	0.23	0.16	1	0.06
2	0.53	0.62	0.2	0
3	0.36	1	0.14	0.56
4	0.45	0.02	0.2	1
5	0.14	0.12	1	1
6	0.75	1	0.57	0.04
7	0.1	0.0038	0.4	1
8	0.13	0.0076	1	1

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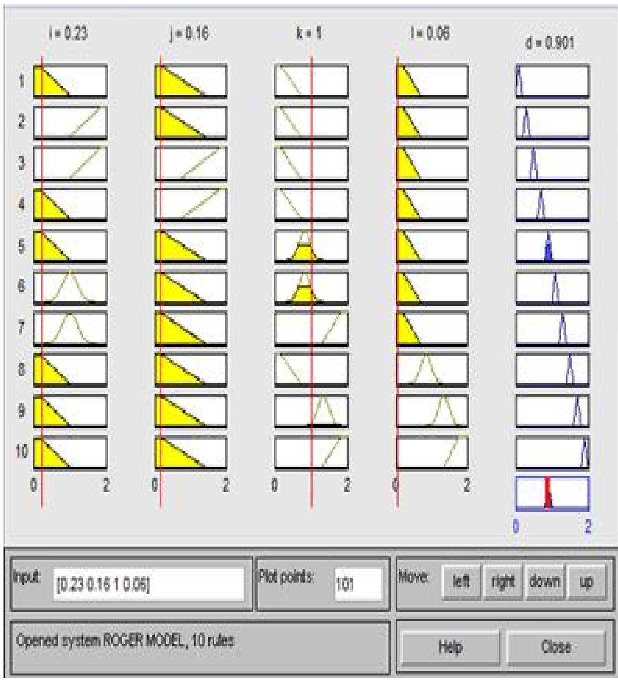
For each sample of faulty transformer oil, a table of Roger Ratio values has been prepared according to the concentration of gases. After that these values converted into fuzzified input variables (i, j, k, l) for the fuzzy system. Thensuitable fuzzy inference rules are applied in order to calculate the fuzzy output (d) which will determine the type incipient faults in the oil samples as shown in figure 2.1 to 2.8.



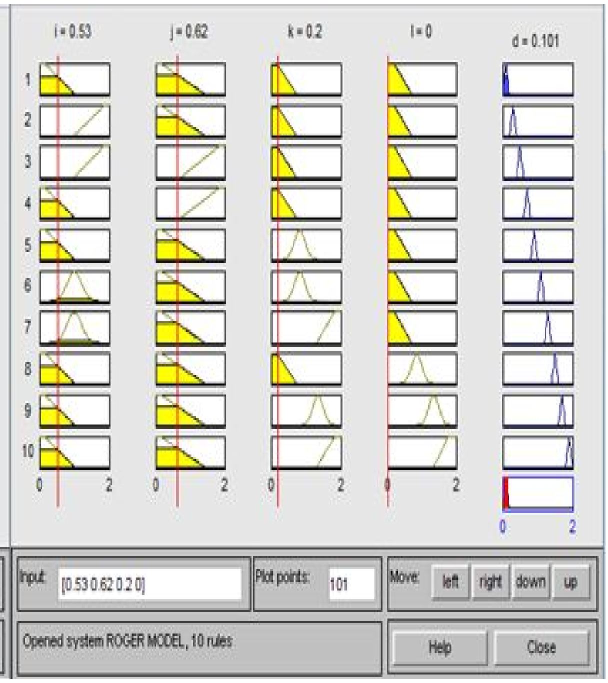
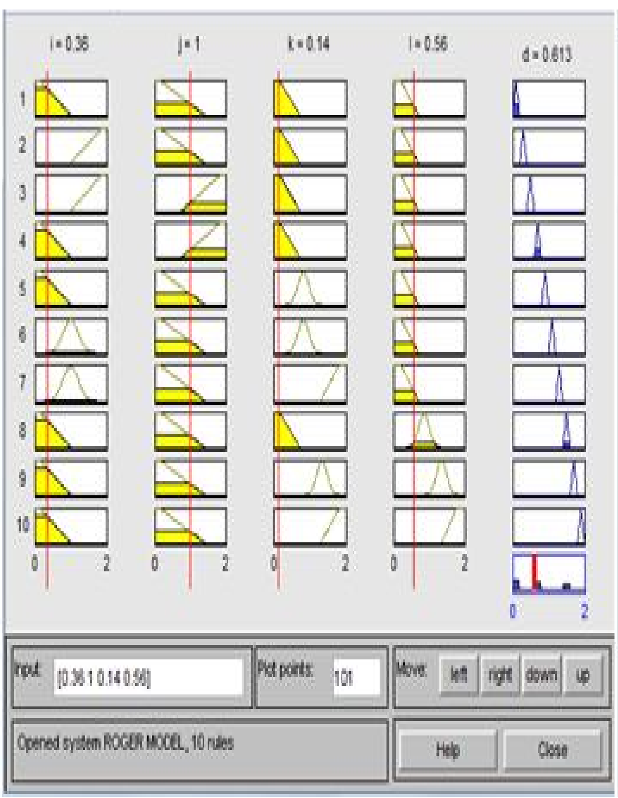


Figure 2.1: I/ O data of FIS for sample no. 1Figure 2.2:I/ O data of FIS for sample no. 2



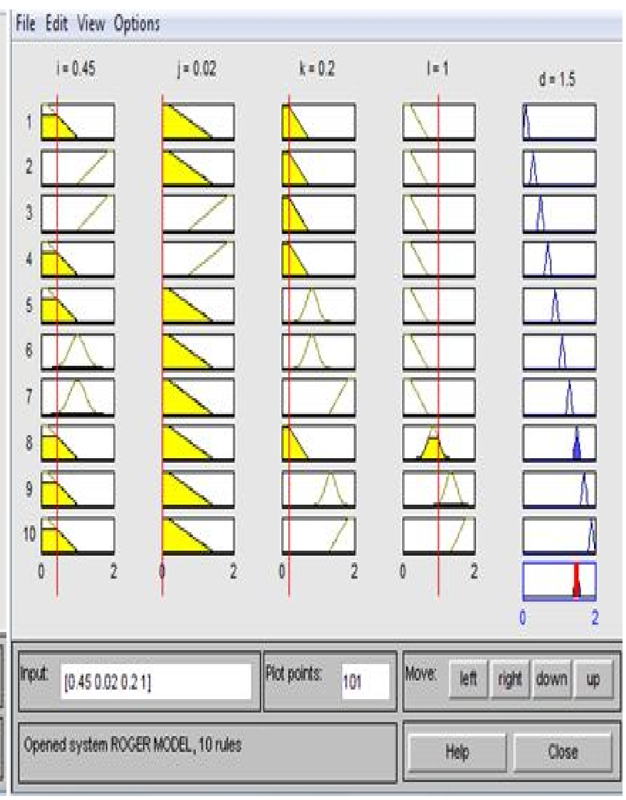
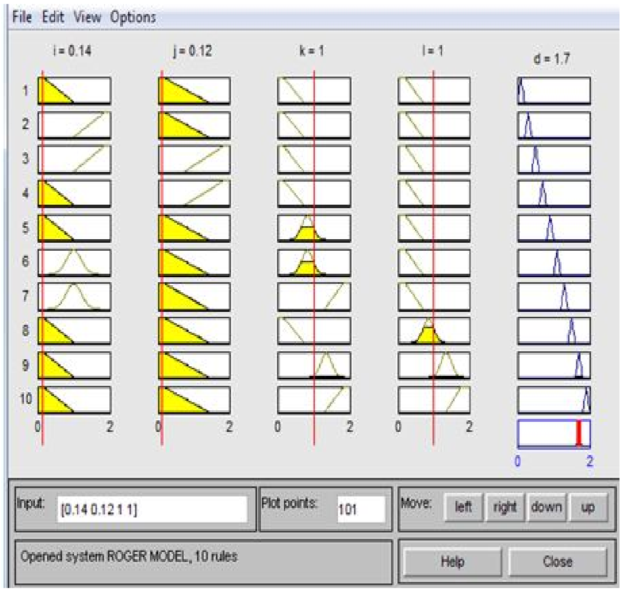


Figure 2.3:I/ O data of FIS for sample no. 3 Figure 2.4:I/ O data of FIS for sample no. 4



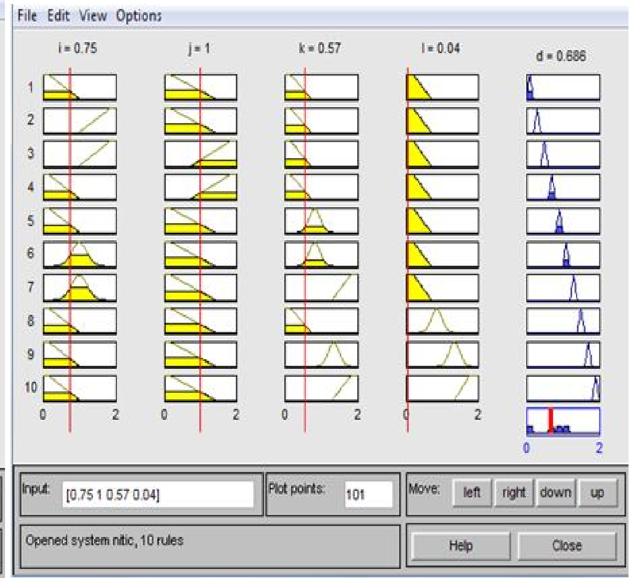


Figure 2.5:I/ O data of FIS for sample no. 5Figure 2.6:I/ O data of FIS for sample no. 6

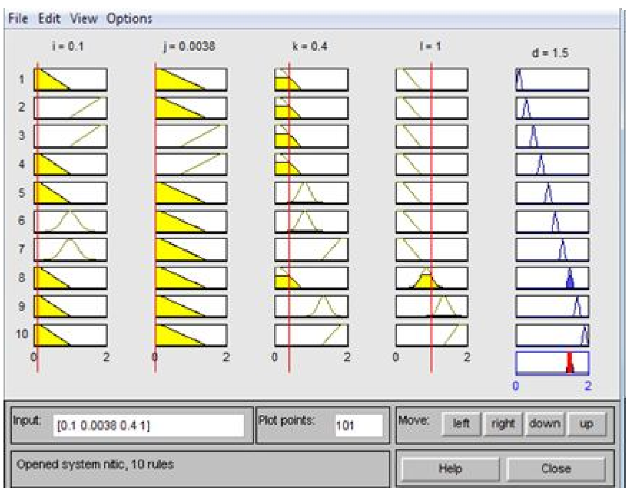


Figure 2.7: I/ O data of FIS for sample no. 7

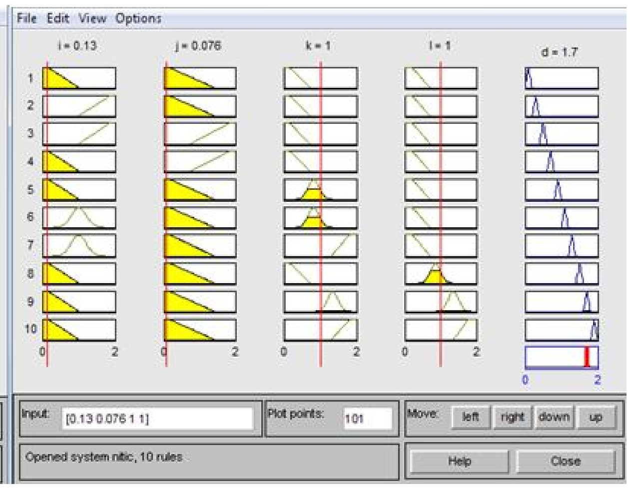


Figure 2.8: I/ O data of FIS for sample no. 8

Therefore total eight different oil samples data have been tested and identified their respective faultdiagnosis results as shown in figures 2.1 to 2.8.

Table5: ROGER'S RATIO ANALYSIS(With Normalized input variable for oil samples)

Sample no	Fuzzy Output (d)	Diagnosis
1	0.901	General Conductor Overheating
2	0.101	Normal Deterioration
3	0.613	Overheating between 200-300 ^{0}C
4	1.5	Flashover Power
5	1.7	Arc with power
6	0.686	Overheating 200-300 ^{0}C
7	1.5	Flash Power
8	1.7	Arc Power

From the results it is clear that by using fuzzy inference system, there are different values of fuzzy outputs(d) for each faulty oil sampleas shown in table5. Therefore, on the basis of fuzzy output values different incipient faults can be detected.So fuzzy infrence system is very much effective and improve the performance of fault diagnosis process.

V. CONCLUSION

The proposed system has been applied successfullyby taking faulty oil samples and its results has been compared with conventional DGA methods. The results show that the diagnosis process is easy,reliable, efficient, insensitive to error in oil sample and better than conventional DGA methods for thedetection of incipient fault in power transformer. Moreover, when there is more than one fault occurring in a transformer then this system may be more useful.

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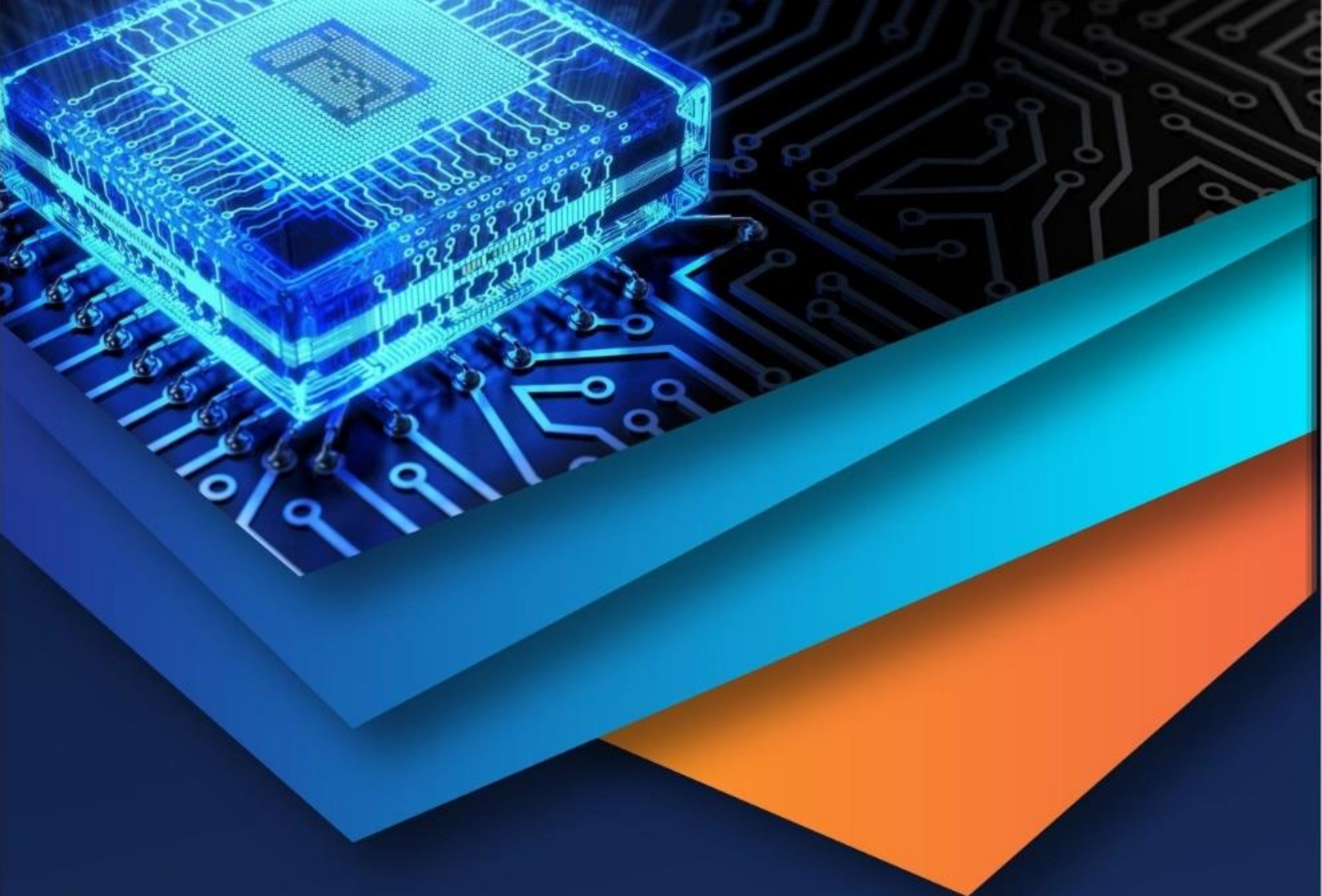

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